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Production of Compressed Stabilized Earth Block (CSEB) from Pulangui Reservoir Alluvial Sediments Using Coal Fly Ash as Partial Replacement to Cement as Binder

Einstine M. Opiso[1], Reinerio P. Supremo[1], Neil P. Daquiado[1], Eva Joy N. Mendoza[2], & King Jehu II Q. Radaza[3]

[1]Civil Engineering Department, College of Engineering, Central Mindanao University
[2]Behavioral Sciences Department, College of Arts and Sciences, Central Mindanao University
[3]Agribusiness Department, College of Agriculture, Central Mindanao University

ABSTRACT

Siltation at Pulangui Reservoir in Maramag, Bukidnon is a big problem for the hydroelectric power plant. This study explores the potential of Pulangui alluvial sediments from five different locations for compressed stabilized earth block (CSEB) production based on the soil consistency and textural properties of sediments and compressive strength of the blocks. The effect of coal fly ash as partial replacement to ordinary portland cement as binder was also examined. The results showed that the soil consistency and textural properties of alluvial sediments failed to pass the suitability criteria for CSEB. Additional sand was added in 1:2 ratio (soil to sand). The replacement of cement with coal fly ash tends to increase its compressive strength up to 20% replacement of cement. The highest compressive strength was observed from the alluvial soils of Panadtalan with 4.32 a . CSEB is viewed to have certain potentials that have the comparative advantage over other materials like hollow blocks but needs a promotional campaign to encourage its usage. The comparative cost analysis revealed that the CSEB with coal fly ash is only 4.30% cheaper compared to the conventional method. Overall, the alluvial deposits of Pulangui reservoir and coal fly ash could be utilized for CSEB production.

Keywords: *Stabilization, Alternative binders, low-cost housing application*

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INTRODUCTION

The siltation problem within the Pulangui reservoir of National Power Corporation (NPC) in Maramag, Bukidnon, Philippines, is one of the challenges of NPC. This problem has already reduced the efficiency of their hydroelectric power plant which could subsequently cause discomfort to the people depending on the hydropower plant for electricity. Moreover, NPC is spending millions of pesos annually in dredging these earth materials which are currently being impounded within the Pulangui reservoir. Also, the siltation sediments are considered to be of no use and could pose serious disposal problems in the future.

One of the potential solutions to solve this problem is to explore its potential as compressed stabilized earth block. Compressed stabilized earth block (CSEB) is the idea of compacting the soil particles composed of clay, sand and a small percentage of cement to reduce voids and increase density which will make the soil suitable for any construction applications such as foundations, load bearing walls, arches, vaults, and dooms. A good soil for producing CSEB could be based on its textural characteristics in which the sand, silt, and clay percentages is around 90-60 %, 25-0 %, 25-0 %, respectively (Gooding, 1993). In terms of Atterberg limits, the plasticity index and liquid limit of the soil should have a percentage of 0-22% and 7-40%, respectively (Spence & Cook, 1983). Portland cement acts as a binder to reduce shrinkage and water absorption in the blocks to suit construction demand including the increase in compressive strength. Moreover, the percentage of the binder needed to stabilize the compressed earth block varies in different soil types, region, and country (Arumala & Gondal, 2007).

On the other hand, coal fly ash (CFA) is an industrial waste from coal-fired power plants. CFA is a fine powder and consists mainly of spherical particles less than 50 microns in size. It possesses pozzolanic properties and has a content which allows it to set and harden through chemical interaction with water called the calcium oxide. By adding CFA to soil, cation exchange, flocculation and agglomeration, carbonation and pozzolanic reactions are believed to occur. According to Adam (2001), the pozzolanic reaction was believed to be the most important, and it occurs between lime (CaO) and certain clay minerals to form a variety of cementitious compounds which bind the soil particles together and could possibly make the CSEB more durable. However, the possibility of utilizing CFA as partial replacement to cement in CSEB production is not yet carried out.

In this context, this study aims to assess the potential of Pulangui alluvial sediments located at Barangays Dologon, Tubigon, Bayabason, Panadtalan and Anahawon in Maramag, Bukidnon in CSEB production using CFA-OPC blend as binder in order to address the siltation problem in Pulangui reservoir as well as the disposal problem of CFA. The optimum amount of CFA was examined by partial replacing OPC at 0, 20, 40, 60, and 80%. The suitability of Pulangui alluvial sediments in for CSEB production was determined based on the textural characteristics, and Atterberg limit tests of the sediments, and the compressive strength of the blocks. Social acceptability and economic profitability assessment were also conducted to determine its potential for low-cost housing applications.

METHODOLOGY

The alluvial deposits were collected within the Pulangui reservoir along the section of Dologon, Tubigon, Bayabason, Panadtalan and Anahawon. Figure 1 shows the sampling points within the Pulangui reservoir. The collected samples were placed inside an airtight plastic bag and were stored before characterization and CSEB production.

Figure 1. Sampling sites at Pulangui River (Google Earth: May 2013)

The collected samples were dried first and were analyzed for particle grain size determination by sieve analysis. Subsamples of sediments were allowed to pass sieve # 40 for Atterberg limit tests (Plasticity Index and Liquid limit determination).

The Atterberg limit determination was conducted by the American Standard for Testing and Materials (ASTM D 4318-10).

An appropriate amount of suitable alluvial deposits from Pulangui reservoir in Dologon, Tubigon, Bayabason, Panadtalan and Anahawon was prepared after drying. The dried alluvial deposits from Pulangui reservoir was mixed with 10% OPC (by dry weight of the sediments) to produce four (4) replicates of control samples. Coal fly ash was mixed as a partial replacement to OPC at 20, 40, 60 and 80% replacement. Water was gradually added into the mix until the desired consistency was reached. The amount of water added to react with the cement was estimated using the dropping test method. The resulting mix was placed into the CSEB molder and was compressed accordingly. The blocks were tested for quality of mixture and density by using a hand-held penetrometer in which the penetration should not exceed 5 mm. After compression, the CSEB was detached from the mold and was cured for 28 days in a hot and humid storage area before testing.

The CSEB samples were tested for its compressive strength using a Universal Testing Machine (UTM) after 28 days of curing. The load was continually applied until cracks or deformations are significantly seen. The recorded load at failure was then recorded for compressive strength calculation. The optimum amount of CFA as a partial replacement for cement was then determined based on the maximum compressive strength.

RESULTS AND DISCUSSION

Atterberg's Limits

Figure 2 shows the suitability of the alluvial sediments from the different sampling sites based on Atterberg's Limits Tests. Generally, the best earth soils for CSEB are those with low plasticity index < 20 since they are suitable for manual compaction (Walker, 1995) and cement stabilization (Riza et al., 2010). As shown in the figure, the plasticity index of alluvial deposits from Tubigon, Bayabason, and Panadtalan was within suitable range of 0-22% while the alluvial deposits from Dologon and Anahawon were slightly higher than 22% with 23.19% and 23.65% respectively. However, these PI values were still less than 35% which could receive proper compaction to enhance their strength and durability characteristics since their (Waziri et al., 2013). With regards to the liquid limit, only the alluvial deposits from Panadtalan were within the 7-40% range with 38.39% liquid limit value. While the alluvial deposits from Dologon, Tubigon, Bayabason, and Anahawon were outside the range having 49.74%, 45.20%, 48.10%, and 49.65% respectively. Based on both PI and LL values, only the alluvial deposits from Panadtalan passed the suitability criteria and while the other alluvial deposits collected from other sites need reconstitution by adding sand to make them suitable for CSEB production.

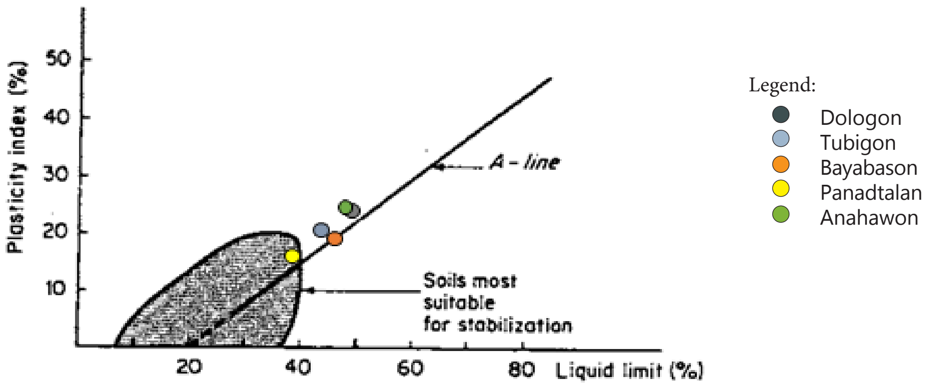

Figure 2. Atterberg's Limit of Samples

Textural Characteristics of Sediments

All alluvial deposits from different sites failed to qualify the ideal sand content of 60-90% as shown in Figure 3A. Dologon showed the lowest sand content with 22.88% while Anahawon exhibited the highest with 57.60%. Their silt contents were beyond 0-25% range with Anahawon as the lowest (34.40%) while Dologon as the highest (68.32%). However, all samples were within the ideal clay content of 0-25% with Bayabason and Panadtalan as the lowest (0.00%) and highest (19.28%), respectively. The failure of alluvial deposits to qualify the ideal soil criteria for soil stabilization suggests that they could still be stabilized by infusing additional sand to reach at least 60%. Although the clay content in the sediments could contribute to its plasticity and cohesive properties, the compressive strength of CSEB from Pulangui alluvial sediments can still be improved if sand is increased since sand reacts well with cement as a binder. The addition of sand which was also collected from the same site using 1:2 ratio improved the sand content of the alluvial sediments to the ideal sand content of 60-90% as shown in Figure 3B. However, the samples from Bayabason and Panadtalan showed slightly higher silt content of 25.66% and 31.99%, respectively.

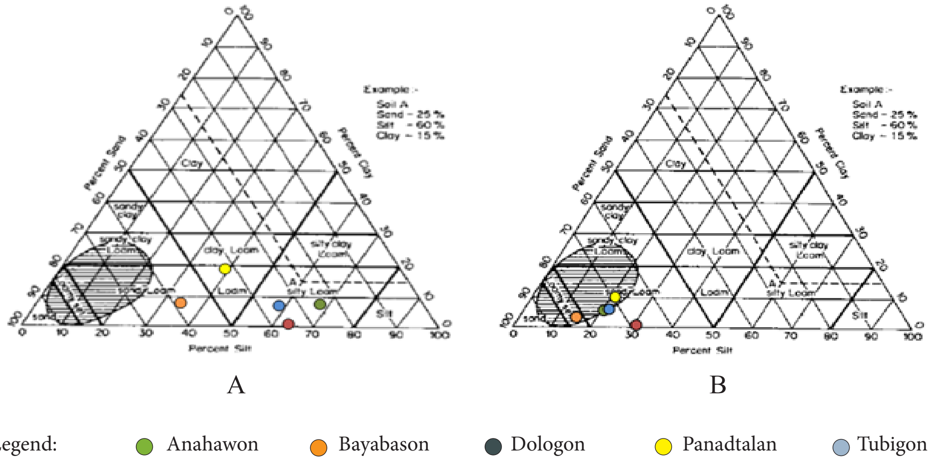

Figure 3. Textural Characteristics of Samples Before (A) and After (B) Addition of Sand

Compressive Strength of CSEB

The results of the compressive strength of CSEB specimens at different percentage of cement replacement by CFA are shown in Figure 4. The compressive strength of CSEB with 10% cement as binder ranged between 2.5 to 3.0 MPa which was greater than the 1 MPa standard requirements. The highest compressive strength was observed from Anahawon alluvial sediments. This may be attributed to the higher sand content of the area. However, the replacement of cement by CFA slightly influenced the compressive strength of CSEB. It can be observed that an increase in the compressive strength of CSEB from 0 to 20% replacement by CFA and decrease after that for higher replacement percentage. The compressive strength of CFA blended cement stabilzer were also higher compared to CSEB samples without cement replacement.

The highest compressive strength of CSEB was observed from the alluvial soils of Panadtalan in which a 4.32 MPa was recorded at 20% replacement of cement. The highest compressive strength observed in this study was comparable and even higher to lime-cement blend stabilized kaolinitic clay (Nagaraj et al., 2014) and cement stabilized borrow pit soil (Waziri et al., 2013), respectively. The observed compressive strength was also higher compared to CSEB samples without cement replacement. This could probably be attributed to the filler effect of CFA and pozzolanic reactions in which Si and Al from coal fly ash react with Ca during cement hydration. As the percentage of coal fly ash increase, the dilution effect to cement as a binder may have attributed the resulting reduction of the compressive strength since coal fly ash reacts slowly during hydration (Weerdt et al., 2011).

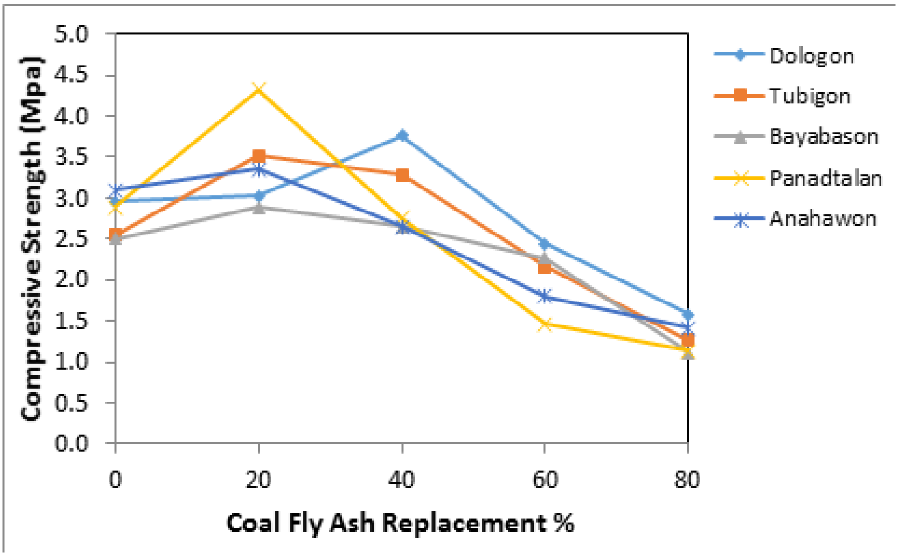

Figure 4. The Compressive Strength of CSEB From the Different Sites Located Along the Pulangui Reservoir with Different Replacement Percentage of Cement by Coal Fly Ash

Social Acceptability of CSEB

The informants identified some strengths of CSEB as summarized in Table 1. They revealed that CSEB has ecological importance because it utilizes silt in the Pulangui River which contributes to flooding and reduces NPC's production of electricity. Another characteristic of CSEB identified by the informants is its capacity to "balance/neutralize" the temperature. Specifically, it provides cooler temperature when the weather is hot while it also gives warm temperature when the weather is cold. They also mentioned that CSEB is durable when properly seasoned or satisfied the prescribed duration. It also has an aesthetic value especially when it is properly aligned. CSEB likewise offers livelihood opportunities for the men and women in rural barangays. It is interesting to note that women are also involved in the production of CSEB. Based on the rough assessment of the informants, CSEB has a lesser cost due to the limited use of cement and less labor required.

On the other hand, the informants mentioned of some limitations of CSEB. There are those who considered CSEB to be just suited for walls/division and not for a foundation. Due to limited research, it is also perceived to be not suited for high-rise buildings. There are also informants who revealed that if CSEB may be hit by a stone or other hard objects, it could be cracked. In producing CSEB, it has also been observed that it requires rigid monitoring in the production and filing. Thus, it requires trained workers because it could hardly be done by just "ordinary" laborers, with no skill developed.

Table 1.
Strengths and Limitations of CSEB

Strengths	Limitations
With ecological/environmental importance	Not suited for foundation and high rise buildings
"Balances" the temperature	May be cracked if hit by stone or other hard objects
Durable especially when seasoned	Requires rigid monitoring in production and filing
Has aesthetic value	Requires trained workers
Provides livelihood	
Less cost	

Comparative Cost Analysis

For the conventional CSEB production, the following assumptions were made. The Salvage value is 5% of the original value of the building. Thus machine, shovel and pale, the original values are based on the actual current prevailing prices in the market, the original value may vary in monthly basis due to regular inflation rates in the market and an average of four (4) operating days per week. Based on the assumptions, the direct cost, and indirect costs, respectively in making CSEB using the conventional method and optimum design mix using coal fly ash were determined. The resulting unit cost of CSEB using the conventional is equivalent to Php 14.55/CSEB while that with coal fly ash as 20% replacement to OPC is equivalent to Php 13.95/CSEB. The CSEB with coal fly ash is 4.30% relatively cheaper than the conventional CSEB as shown in Table 2. Their difference is attributed to the cost of cement and coal fly ash since the cost of producing the CSEB varies on their direct material cost. However, the direct labor cost of both kinds of CSEB has an average contribution of 50.51% of the total unit cost, thus, the laborer should increase their capacity to reduce its cost per unit efficiently.

Table 2.
Comparison of Cost Analysis of Conventional CSEB and CSEB with Coal Fly Ash

A. DIRECT COST	Conventional CSEB	CSEB with Fly Ash
Direct Material		
Cost of Alluvial Soil	1.89	1.89
Cost of Commercial Cement	4.43	0.00
Cost of Portland Cement and Fly Ash	0	3.83
Unit Direct Material Cost	6.32	5.72
Direct Labor		
Cost of Making the CSEB	7.14	7.14
Unit Direct Labor Cost	7.14	7.14
B. INDIRECT COST		
Cost of Making and Holding the CSEB	1.089	1.089
C. UNIT COST	14.55	13.95

CONCLUSION

The alluvial deposits along Pulangui reservoir, particularly at Dologon, Tubigon, Bayabason, Panadtalan, and Anahawon, were composed mainly of sand and silt and traces of clay. Based on Atterberg's limit and textural compositions, alluvial deposits from the reservoir failed to meet the suitability criteria for CSEB production and addition of sand is needed using a 1:2 ratio (soil to sand). The compressive strength of CSEB samples reached the required capacity of 1 MPa after 28 days of curing. CSEB generated from Anahawon site showed the highest compressive strength of 3 MPa using 10% of cement (by weight) as binder. The blending of cement with coal fly ash as cement replacement up to 20% increased the compressive strength of CSEB. The CSEB generated from Panadtalan site showed the highest compressive strength of 4.32 MPa. Moreover, CSEB is viewed to have certain potentials over other materials like hollow blocks and slightly cheaper compared to the conventional method. In brief, the alluvial deposits of Pulangui reservoir could be utilized for CSEB production and be applied for low-cost housing applications provided that proper stabilization and socio-economic interventions are carried out.

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